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ECONOMICS OF STORAGE AND SPREADING OF LIQUID MANURE FOR FEEDER HOGS IN ONTARIO

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ECONOMICS OF STORAGE AND SPREADING
OF LIQUID MANURE

for

FEEDER HOGS
IN ONTARIO

by

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ECONOMICS OF STORING AND SPREADING OF LIQUID MANURE FOR FEEDER HOGS IN ONTARIO

Since the early 1960's livestock production in Ontario, as elsewhere in North America, has witnessed a rapid growth in the trend towards confinement production. This trend has been particularly prominent in the production of poultry and feeder hogs. Coupled with this development towards confinement production has been the development of the liquid manure system. For many farm operations the problem of animal waste management has become critical. Morris has pointed out that failure to find an acceptable method of disposal at a sufficiently low cost may oblige producers to terminate production at certain locations.^{8/}

In an effort to indicate the dimensions of the animal waste disposal problem, the Soils Department at the University of Guelph^{5/} has suggested the following animal enterprises have a waste disposal problem comparable to a city of 10,000 people:

- (i) 500,000 chicken broilers
- (ii) 50,000 laying hens
- (iii) 5,000 market hogs
- (iv) 1,000 beef cattle
- (v) 500 dairy cattle per year.

Dale^{3/} points out that in the United States, the total quantity of wastes produced annually by livestock is approximately ten times greater than the quantity produced by humans. He notes further that livestock wastes are being accused of polluting air, soil, and water resources. Again Taiganides^{9/} reports that in 1964 the United States Public Health Service reported that approximately 1.1 million fish were killed because of manure discharge into rivers and lakes. Although this was estimated to be only 6.5% of the total number of fish killed by pollution, it is clear that the pollution potential of large agricultural operations is very significant.

The Producers' Problem

Today, with the development of the commercial fertilizer industry and the rapidly increasing cost of farm labor, the question of whether or not the value of manure represents a positive net value to the hog operation after storage, spreading, and handling costs are deducted is repeatedly being asked. Morris suggests that the concept of obtaining maximum profit from the use of livestock manures is rapidly giving way for large scale producers to the concept of disposing of the manure at minimum cost and below a certain 'nuisance' level. An Illinois study^{6/} in 1967 estimated that when the total manure supply was hauled and spread, a positive manure value per hog of approximately \$0.20 was realized after spreading costs were deducted when the hog operator was marketing 1,500 hogs per year. The study estimated that a negative return over spreading costs was realized when only 500 hogs were marketed annually.

Research at Guelph and at other centers throughout the world has attempted to show the chemical analysis of liquid hog manure in terms of the primary nutrients, N, P_2O_5 , and K_2O , that are contained in the manure. Estimates of the organic matter content and of the minor chemical elements have also been made.^{1/} The research results to date suggest a reasonable degree of agreement as is seen in Table 1.

While it would clearly have been preferable to have access to research results when valuing the hog manure during different seasons of the year, this was not possible. Production function data were not available for Ontario conditions. It was therefore necessary to choose arbitrary values for applications of liquid hog manure at different seasons of the year.^{7/}

The two main factors affecting the economically optimal storage capacity and the net value of manure produced on the farm were considered to be:

- (a) the density of hogs per acre of land available for spreading manure, and
- (b) the crop(s) under cultivation.

The density of hogs per acre was felt to be significant since it was assumed that the hog operator was willing to comply with good farm practice and was not prepared to apply manure to the land at such a rate that it would be likely to contribute to our pollution problem. The crops being cultivated were of significance since different crops were inaccessible at different times and since the manure absorption capacity of different crops varies.

Storage Tanks

In the study, 136 feeder hog operators in Ontario supplied data pertaining to their hog herds and liquid systems. The average storage capacity per farm was 3½ months. The typical investment cost range was from 3 to 7 cents per gallon capacity, with some 70% of the operators falling within this range. The average investment cost was 5 cents per gallon capacity. Morris^{8/} had suggested a typical investment cost per U.S. gallon capacity of 4 to 7 cents. In the study, the storage tanks were written off over a 10-year period. Morris^{8/} also used a 10-year period, while Casler and LaDue^{2/} used a 15-year period. No significant investment economies of scale were found to exist. Table A3 in the Appendix presents the annual costs associated with storing.

Spreading Operation

It was expected that significant investment economies of scale would accrue to large scale producers because of the high initial cost and the short life expectancy of the equipment. Morris^{8/} chose to write the spreading tank off over a 10-year period, while Casler and LaDue^{2/} chose a 5-year period. A 7-year write-off period was suggested by a number of Ontario equipment manufacturers, and this rate was used in the analysis. Tables A1 and A2 in the Appendix show the estimated annual fixed costs associated with the impeller and vacuum spreading units.

The estimate of the investment cost in impeller-type systems (including pump) was \$1,750 on average while the vacuum system was estimated to have an average investment of \$1,350. The annual investment costs of the impeller and vacuum systems were estimated at \$415 and \$293 respectively.

The impeller system was estimated to have an average capacity of 1,000 imperial gallons while the vacuum system had an average capacity of 850 imperial gallons.

The average number of trips made per hour was found to be 3.4 with the impeller system and 3.1 with the vacuum unit. A north Carolina study^{11/} had found that it took 6 minutes to load a 1,200 gallon spreader and 15 minutes to haul and spread a load of manure. Morris^{8/} estimated that with a 750-gallon vacuum spreader a total of 22 minutes would be needed per load. These estimates are in close agreement with the above findings.

Kesler^{6/} observed that spreading tanks are typically filled to 90% of capacity so that when this assumption was applied to the data, the average volume of manure drawn per hour was estimated to be 3,060 and 2,350 imperial gallons with the impeller and vacuum systems, respectively. Assuming these volumes of manure are moved per hour, and using a standard \$2 per hour charge for labor, and an estimated tractor operating charge of \$1.65 and \$1.45 per hour when the impeller and vacuum units are assumed to be drawn respectively, the variable costs associated with spreading are estimated to be \$3.65 per hour or \$1.19 per 1,000 imperial gallons with the impeller unit, and \$3.45 per hour or \$1.47 per 1,000 gallons with the vacuum unit.

Total spreading costs for herds of 500 and 3,000 hogs were found to range from \$6.07 to \$1.96 per 1,000 gallons with the impeller system, and \$5.01 to \$2.03 per 1,000 gallons with the vacuum system.

Value of Liquid Hog Manure

As explained, liquid manure in this study is valued on the basis of its replacement value for commercial fertilizer nutrients of N, P₂O₅, and K₂O. Manure produced on different farms can vary to a very considerable degree. Kesler^{6/} compared 34 samples from different farms and found a wide variation in the dry matter content and the fertilizer elements of N, P₂O₅, and K₂O. However, both he and Taiganides^{9/} found that when the N, P₂O₅, and K₂O contents of the samples are related to dry matter content, a high degree of linear correlation is found to exist. Table 1 presents the findings of various research groups to date, including the analysis of 51–29–18 pounds of N, P₂O₅ and K₂O respectively per 1,000 gallons of liquid hog manure that was estimated at Guelph. A dilution factor of 40% was assumed in the above analysis.^{4/}

No production function data were available regarding the fertility value of liquid manure applications during different seasons of the year so that arbitrary seasonal estimates were used. The justification for them is that they represent a departure from the traditional methods of valuing manure. The specific approach was to discount liquid manure applications for their effectiveness compared with commercial fertilizer applied in the spring months.

Spring Applications of Liquid Hog Manure

It was estimated that the nitrogen, phosphorus and potash in liquid hog manure were approximately as effective when applied in the spring as the same nutrients applied in the form of commercial fertilizer, although the nitrogen in the manure may become available at a slower rate.^{7/} Thus using the estimated 1969 Ontario prices of 10¢, 10¢ and 4.8¢ per pound of N, P₂O₅ and K₂O respectively, a load of 1,000 gallons of liquid hog manure with the analysis of 51–29–18 pounds of N, P₂O₅ and K₂O respectively will have a value of \$8.86. Thus the study assumed that applications in the months of April, May, and June will have an approximate value of \$8.86 per 1,000 gallons spread.

Summer Applications of Liquid Hog Manure

The availability of land to utilize the nutrients supplied in liquid hog manure will be determined by the crops under cultivation. In Ontario, for operators with all corn, it is not possible to gain access to the land for spreading manure during the approximate period from June 20 to October 20 so that it is possible that such operators will realize no value for manure produced during this period unless it can be stored or sold. Where the manure can be applied to another crop during this period the manure applications are estimated to be as valuable as they were in the spring.^{7/}

Fall Applications of Liquid Hog Manure

It was estimated that the phosphorus and potash in the manure are utilized by the crops as efficiently as they were in the spring while approximately half of the nitrogen applied in the fall period is believed to be lost and is not utilized by the crop so that a pound of N thus applied was discounted 50% compared with a pound of N applied in commercial fertilizer in the spring.^{7/} For fall applications, therefore, a pound of N was valued at 5¢. A 1,000-gallon load spread in the fall would, therefore, have a value of \$6.31.

Winter Applications of Liquid Hog Manure

Under Ontario conditions significant nutrient losses are thought to occur when manure is spread during the winter months. The losses are largely due to runoff since the land will be covered by ice and snow for much of the period. It is realized that the runoff loss will vary considerably from one farm to another, but an average runoff figure was estimated to be 60%. It is suggested, therefore, that each of the nutrients should be discounted by 60% for runoff loss and that in addition the nitrogen should be discounted a further 20% for denitrification.^{7/} The values per pound of N, P₂O₅ and K₂O applied in the winter months are thus estimated at 2¢, 4¢, and 2¢ respectively. An estimated value for a 1,000-gallon load of manure spread during the period is approximately \$2.54.

Pollution Considerations

Liquid manure differs from commercial fertilizer again in that an excess volume of manure and, therefore, plant nutrients may be made available on the farm. The problem arises as to how excess supplies of plant nutrients should be valued.

The approach adopted in the study was to first value applications of N, P₂O₅ and K₂O contained in liquid manure up to the point where an economic optimum is reached. Theoretically, this economic optimum point will be where the marginal value product of the crop to which the manure is applied will be equal to the marginal factor cost of the manure input. However, beyond this level of application, excess manure may well be on hand so that it becomes necessary to value additional supplies of manure in some way. Clearly, to apply the same value to this supply as to those nutrients applied before the economic optimum is reached, would be to ignore the marginality principle of economics.

Since the additional nutrients are available, however, they should be applied to the crop to increase production. Since no research is available that can show the marginal value product with respect to successive units of liquid manure, it was necessary to arbitrarily value surplus applications of liquid manure beyond the economic optimum level. It was considered reasonable to arbitrarily value surplus applications of nutrients at a level of 50% of the value that was attributed to nutrients applied before the economic optimum was reached.^{7/}

Such applications may be termed 'low value' applications to facilitate the presentation, while applications before the economic optimum is reached will be termed 'high value' applications. These values are represented in Table 2.

Table 2. Value per Pound of N, P₂O₅ and K₂O Spread Throughout the Year at 'High' and 'Low' Values

	January February March	April May June	July* August September	October November December
High Values:				
N	2	10	10	5
P ₂ O ₅	4	10	10	10
K ₂ O	2	4.8	4.8	4.8
Low Values:				
N	1	5	5	2.5
P ₂ O ₅	2	5	5	5
K ₂ O	1	2.4	2.4	2.4

*If land is available

A point may also be reached, however, beyond which additional applications of nitrogen may cause contamination of surface and ground water by nitrate nitrogen. The Department of Soil Science at Guelph suggests that an arbitrary way of arriving at this level for corn is to double the rate of application that can be efficiently* used up by the corn. Specifically, they suggest that an application of 155 pounds of N is consistent with efficient crop utilization and that an application of 310 pounds of N per acre of corn is the approximate ceiling level consistent with a policy that aims to avoid pollution.^{10/} The former rate of application has been termed the economic optimum rate of application and the latter rate the pollution control level of application by the Department of Soil Science. For barley and hay-pasture, which were also considered in the study, the pollution control levels were estimated to be 150 pounds of N per acre.**

Good farm practice should ensure that an operator who reaches this application level and who still has a supply on hand will attempt to have his neighbor take the surplus. If this cannot be arranged, he should be prepared to spread the manure on his neighbor's farm at a cost to himself. This was the typical situation found in the data collection period. Typically, the disposal of surplus manure on neighboring farms took more time than was necessary to spread manure on the home farm. The assumption made in the study was that approximately twice as much time was needed, so that approximately 1,500 gallons were assumed to be moved per hour.

Volume of Manure Produced

Table 3 shows various estimates of manure production per hog on a daily basis. The Guelph estimate which was used in the analysis suggested an average monthly volume of production of 4.1 cubic feet or 1.15 imperial gallons per day. A 40% dilution factor is included.^{4/}

*Economic efficiency

**One-third legume stand is assumed for hay pasture.

Table 3. Average Daily Manure Production per 1,000 lb of Liveweight and per 125-lb Hog as Estimated in 7 Selected Studies

Source	Average daily manure production/1,000 lb of liveweight (lb)	Average daily manure production/1,000 lb of liveweight (imp gal)	Average daily manure production/125-lb hog (imp gal)
Hazen	99	9.88	1.23
Davis	98	9.78	1.22
Salter and Schollenberger	98	9.78	1.22
Hart	86	8.58	1.07
Robinson	100	9.09	1.23
Taiganides	70	6.09	0.86
Kesler	93	9.03	1.16
Average of 7 studies	92	9.16	1.14

For the farms reporting in the study the average turnover of hogs per year was 2.5, so that each hog was assumed to be in the building for approximately 146 days and approximately 170 imperial gallons are assumed to be drawn per hog throughout the life of the hog.

Maximization of the Value of Manure Produced on the Farm

In order to determine the economically optimal storage tank capacity, it is necessary to define the farm in terms of herd size, farm acreage, and crops under cultivation. In the study, 30 farms were defined in this way, and were based on the types of farm found in the data collection period.

Crop Accessibility

Table A4 in Appendix A presents the periods during which the different crops were thought to be inaccessible because of crop growth. To facilitate the analysis, the year was broken down into 19 different time periods. The months of April to October inclusive were each broken down into 10- and 20-day periods, while the remaining months were not broken down.

Assumptions with Regard to Plant Nutrient Requirements

Tables 4 and 5 list the economic optimum and pollution control levels of application for the three different crops considered.

Table 4. Economic Optimum Application of N, P₂O₅ and K₂O Assumed in the Study for the Three Different Crops Considered^{7/}

Crop	N (lb)	P ₂ O ₅ (lb)	K ₂ O (lb)
Corn	155	60	80
Barley	60	40	40
Hay-pasture (1/3 legume)	60	50	100

Table 5. Pollution Control Levels of Application of N, P₂O₅ and K₂O Assumed in the Study for the Three Different Crops^{7/}

Crop	N (lb)	P ₂ O ₅ (lb)	K ₂ O (lb)
Corn	310	176	109
Barley	150	84	52
Hay-pasture (1/3 legume)	150	84	52

Method of Analysis

Since the hog operator is typically faced with a number of alternative courses of action in the pursuit of his manure value maximization objective and, since there are a number of restrictions that impede him as he attempts to fulfill this objective, it was felt that the problem might be stated in such a form that the linear programming technique could be applied in order to maximize the objective function of the hog operator.

The linear programming model that was developed enabled farms to be depicted in terms of equations and restrictions so that the determination of the fertilizer value of the manure net of storage cost and the determination of the economically optimal storage tanks capacity became possible. The specific objective of the linear programming model was to determine the economically optimal spreading pattern for the liquid manure and the economically optimal storage capacity, and it thus maximizes the value of the manure produced on the farm.

Mathematical Statement of the Model

Find the quantities x_j ($j = 1$ to 135) to maximize the value of manure produced on the farm net of storage cost and disposal cost off the farm, where applicable.

$$\text{i.e.: Maximum} = \sum_{j=20}^{76} p_j x_j + \sum_{j=77}^{133} p_j x_j + 1 \times 134 + \sum_{j=135}^{153} p_j x_j$$

subject to the sets of pertinent restrictions

$$\sum_{j=1}^{153} A_{ij} x_j \leq b_i \quad (i = 1, 2, \dots, 121)$$

and the non-negativity restrictions $x_j \geq 0$

Variables

Where $X_{20} - X_{76}$ represent the quantities of N, P_2O_5 and K_2O in the manure that is spread at 'high value' during the 19 different time periods.

Similarly, $X_{77} - X_{133}$ represent volumes of N, P_2O_5 and K_2O spread at 'low value' during the same periods. X_{134} represents the capacity of the storage tank in terms of imperial gallons. $X_{135} - X_{153}$ represent the volume of manure that the hog operator elects to dispose of on neighboring farms at a cost to himself during each of the 19 time periods.

Essentially, the model determines whether it is better from an economic standpoint to spread the manure monthly, to store the manure until such time as it can most effectively be used up by the crop, or to dispose of it on neighboring farms at a cost to the hog operation.

Restrictions

The restrictions confronting the hog operator in his choice of a course of action include the following:

(a) An upper limit on the economic application of manure to the crop as was specified in Table 4.

(b) A pollution control ceiling level of application to the different crops as was specified in Table 5.

(c) The hog operator is restricted from gaining access to the crop during periods of crop growth so that manure will either have to be stored or disposed of on neighboring farms at that time.

(d) The plant nutrients in the manure are held and must be applied in a fixed ratio unlike the case with commercial fertilizer.

In the model, farm acreage was defined through specifying the upper limit for the volume of manure that could be applied to the land; herd size was defined through specifying the volume of manure produced per month; and the crop(s) under cultivation was defined through specifying the plant nutrient requirements and the periods during which access to the crop was impossible because of crop growth.

Results Determined by the Model

The hypothesis that the hog per acre ratio and the crop(s) under cultivation would influence the determination of the economically optimal manure storage tank capacity was supported. The economically optimal manure storage capacity expressed in months varied from 1.8 months to 4.5 months as the combination of crop(s) under cultivation and the hog per acre ratio varied. Two 150-acre farms growing all corn and marketing 3,000 and 1,000 hogs respectively per year were determined to have economically optimal storage capacities of 3.1 months and 4.5 months respectively. The assumption that had been made was that the hog operator could elect to dispose of unwanted manure at a cost to himself that was double the estimated cost of spreading on his home farm. Explaining the larger economic optimum size of storage for the 1,000-hog farm is the fact that the manure cannot be as effectively used on the farm with 3,000 hogs as it can on the farm with 1,000 hogs, since too great a supply is on hand to be economically utilized by the crop so that the return in manure value per dollar invested in storage is not as great as it is for the farm with 1,000 hogs.

The crop(s) under cultivation was also found to influence the size of the storage tank that proved economically optimal. It was seen, for instance, that a 150-acre farm, with 3,000 hogs, growing all corn had an economic optimum storage capacity of 3.1 months, while a similar farm growing barley had an economic optimum of 2.6 months, notwithstanding the fact that the period during which the crop was inaccessible due to crop growth was of equal duration for each crop. Explaining the difference is the fact that the plant nutrients in the manure can be better utilized by the farm growing corn than they can by the farm growing barley, since the plant nutrient requirements are higher for corn than for barley.

The analysis also showed that for farms growing more than one crop, the economically optimal storage capacity tended to be lower than for single crop farms. With a combination of corn and barley, for instance, the period during which both crops were inaccessible was reduced since the crops are not planted and harvested at the same time. A 250-acre farm growing half corn and half barley, and marketing 1,000 hogs per year was estimated to have an economically optimal storage capacity of 2.5 months, while a similar farm with hay-pasture instead of barley had 1.8 months of storage capacity as its economic optimum.

Value of Manure Produced After Storage and Disposal Costs (if applicable) are Deducted

The analysis determined that the manure value per hog ranged from \$1.06 to -\$0.10 for the 'typical' farms considered. A 100-acre farm with an annual herd of 500 hogs that grows half corn and half barley was found to have a net value of \$1.07 per hog, while an intensive livestock unit with 50 acres of grass that markets 3,000 hogs annually had a negative net value after storage and disposal of -\$0.10. Typically, it was found that farms with lower hog per acre ratios had higher manure values per hog since the manure was better utilized on these farms.

Net Value of Liquid Manure After Storage, Spreading and Disposal Costs (if applicable) are Deducted

The hypothesis that significant economies of scale would accrue to those operators with large herds because of the relatively high fixed costs associated with spreading was supported so that after the spreading costs were deducted together with the storage and disposal cost (if applicable), those operations with large herd sizes had a higher manure value per hog than those with smaller herds.

For example, a farm with 3,000 hogs and 150 acres growing all corn had a manure value net of storage and disposal cost of \$0.61 compared with \$1.07 for a farm with 500 hogs and 100 acres growing half corn and half barley, whereas, after the spreading costs were also deducted, the manure value per hog changed to \$0.28 and \$0.05 respectively. Significant economies of scale are seen to apply to the spreading operation.

Table A5 in the Appendix shows the net value of the manure for three 150-acre farms growing all corn. Although the 1,000-hog farm had the highest manure value per hog on a per 1,000-gallon basis, the 2,000-hog farm had the highest net value after spreading costs were deducted. The net value per hog was higher on the 2,000-hog farm than on the 1,000-hog farm partly because of the distribution of the spreading costs over a larger number of hogs. The distribution of the spreading costs over a still larger herd of 3,000 hogs was not, however, responsible for increasing the net value of the manure per hog still further, as the manure was less effectively used on this farm since a surplus of plant nutrients was made available through the manure supply. On the other hand, for farms with barley, the value of manure per hog net of spreading cost was greater for the 1,000-hog farm than it was for either the 2,000- or 3,000-hog farm. Table A6 presents these results. Explaining the

APPENDIX

Table A1 Annual Fixed Cost for the Impeller-type Spreading Unit (including pump) with an Investment Cost of \$1,750

Annual cost — depreciation (14.25%)	\$249.37
Interest on investment (8% of average investment value)	70.00
Repairs and maintenance (5%)	87.50
Insurance (0.5%)	8.75
TOTAL	\$415.62

Table A2 Annual Fixed Costs for the Vacuum-type Spreading Unit (spreading tank and pump form one unit) with an Investment Cost of \$1,350

Annual cost — depreciation (14.25%)	\$192.37
Interest on investment (8% of average investment value)	54.00
Repairs and maintenance (5%)	40.00
Insurance (0.5%)	6.75
TOTAL	\$293.12

Table A3 Presentation of the Annual Cost of Storage per Imperial Gallon Capacity for a Storage Tank with an Initial Investment Cost of 5 Cents per Gallon Capacity and with a Write-off Period of 10 Years

Annual Cost	
Depreciation and interest $5¢ \times 0.14903$	= \$0.00745
Tax and repairs (1% + 1%)	= \$0.001
Total annual cost/imperial gallon capacity	= \$0.00845
Total annual cost/1,000 imperial gallon capacity	= \$8.45

Table A4 Periods During Which it is Assumed to be Impossible to Gain Access to the Crop for Manure Spreading in Ontario Conditions

Crop	Period
Corn	June 20 — October 20
Barley	April 20 — August 20
Hay pasture	May 20 — June 20
	July 1 — July 20
	August 1 — August 20

Table A5 Presentation of Economically Optimal Manure Storage Capacities and Manure Values per Hog for Three 150-acre Farms Growing All Corn

Number of hogs	Number of acres	Crops	Economically optimal manure storage capacity	Value of manure per hog net of storage cost and disposal cost (if applicable)	Net value of manure/hog after deduction of storage, spreading and disposal cost (if applicable)
1,000	100	corn	4.5	\$0.81	\$0.21
2,000	150	corn	3.3	\$0.77	\$0.37
3,000	150	corn	3.1	\$0.61	\$0.28

Table A6 Presentation of the Economically Optimal Storage Capacities and Manure Values per Hog for Three Farms Growing All Barley

Number of hogs	Number of acres	Crops	Economically optimal manure storage capacity	Value of manure per hog net of storage cost and disposal cost (if applicable)	Net value of manure/hog after deduction of storage, spreading and disposal cost (if applicable)
1,000	150	barley	4.5	\$0.95	\$0.35
2,000	150	barley	3.1	\$0.63	\$0.23
3,000	150	barley	2.6	\$0.49	\$0.17

Table A7 Presentation of Economically Optimal Manure Storage Capacities and Manure Values per Hog for Two Farms Growing a Combination of Corn and Barley

Number of hogs	Number of acres	Crops	Economically optimal manure storage capacity	Value of manure per hog net of storage cost and disposal cost (if applicable)	Net value of manure/hog after deduction of storage, spreading and disposal cost (if applicable)
1,000	250	(125 acres corn) (125 acres barley)	2.5	\$1.07	\$0.47
3,000	250	(125 acres corn) (125 acres barley)	2.5	\$0.98	\$0.65

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